Tritium Effects on Containment Alloys (U)




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SAVANNAH RIVER NATIONAL LABORATORY

We Put Science To Work

Hydrogen Isotopes and Helium in Materials
April 14, 2005

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Objectives

- Support tritium packaging safety & reliability
- Increase understanding of tritium & helium effects on materials.
- Define conditions that lead to tritium-induced crack growth in fielded reservoirs
- Measure mechanical properties, fracture toughness & crack growth rates of alloys as a function of hydrogen isotope and helium content
- Investigate role of forged and welded microstructures on tritium compatibility

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Background and Tritium Testing Requirements

- Reservoir loading, unloading, reclamation, surveillance and life storage testing conducted at SRS.
- High-pressure hydrogen, tritium exposure and sample storage for aging data;
- Electric-discharge machining for unexposed and tritium-exposed components (online FY06) for sample preparation;
- Mechanical & fracture toughness testing and crack-growth rate monitoring for tritium-exposed samples;
- Contaminated metallography, scanning and transmission electron microscopy for investigating hydrogen and helium effects in metals

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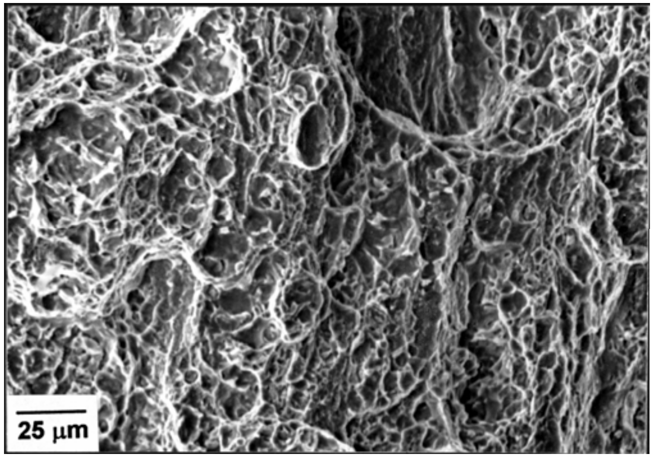
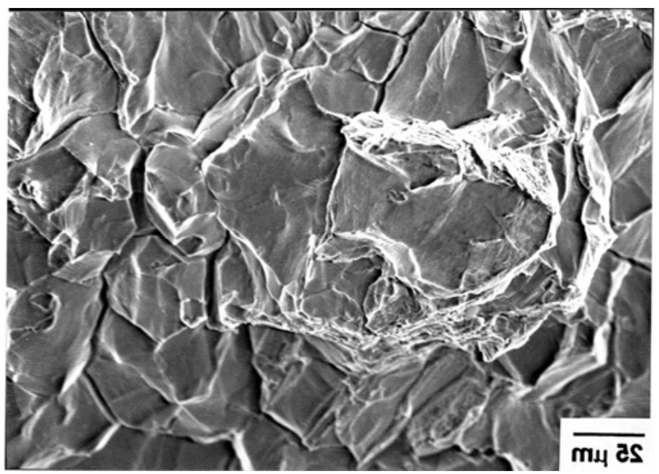
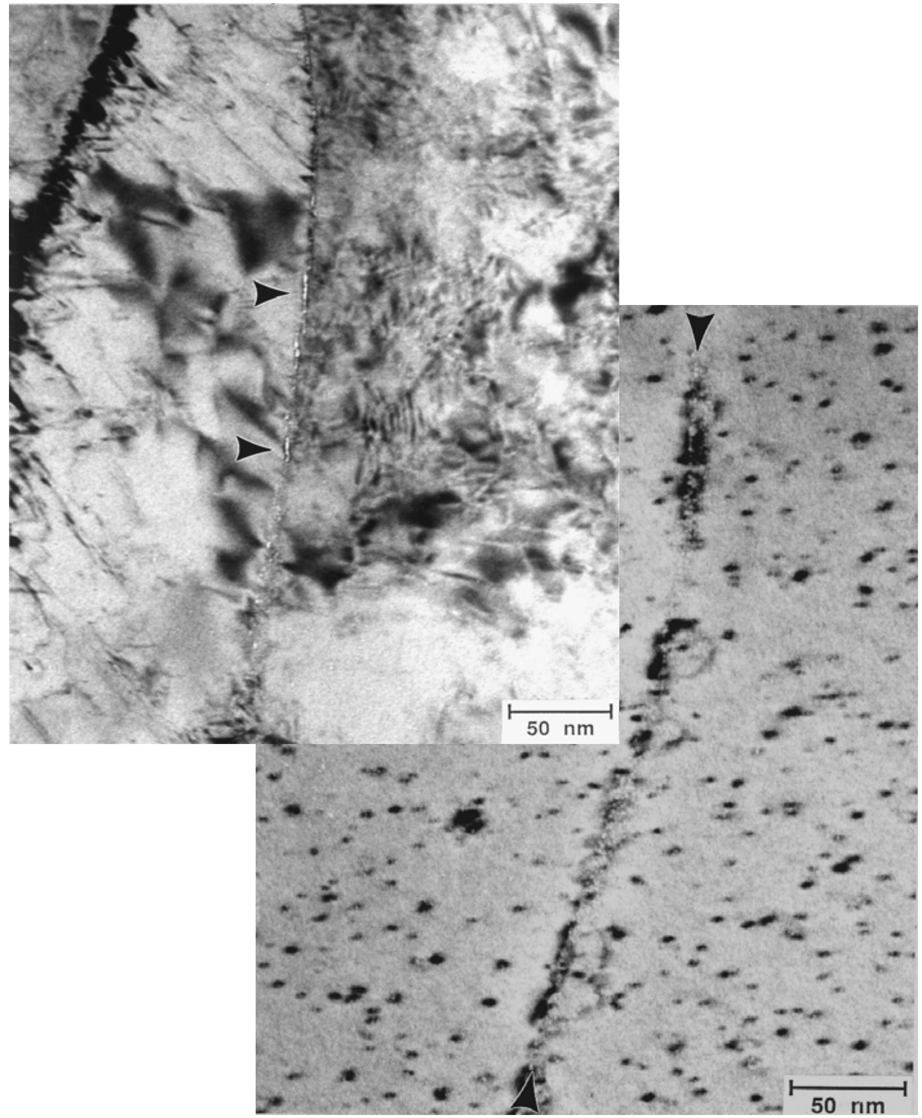
Effect of Tritium Exposure on Stainless Steels



Unexposed



Tritium-Exposed & Aged



Current Investigation: Weldment Test Matrix

- Types 304L and 21-6-9 stainless steels and their weldments;
- Automatic Gas Tungsten Arc Welding;
- Ferrite Contents: 4, 8, 12, 30% achieved by using different filler wires
- Hydrogen and tritium exposures up to 10000 psi, 350 C;
- Helium contents up to 1000 appm achieved by exposure to tritium and aging for decay to helium;
- EB welds also under investigation.

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Accomplishments

- Weldment microstructures characterized and fracture toughness measured for unexposed, hydrogen and tritium-exposed-and aged steels.
- Weldments toughness shown to be higher than the base metal toughness for normal weld ferrite contents
- But, toughness depends on ferrite content & morphology.
- Hydrogen/Tritium charged weldments had lower toughness than base metals and the toughness decreased with increasing weld ferrite content.
- Weldment toughness did not decrease with aging because of reduced tritium contents from rapid off-gassing from weldment.

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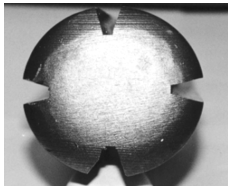
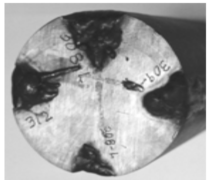
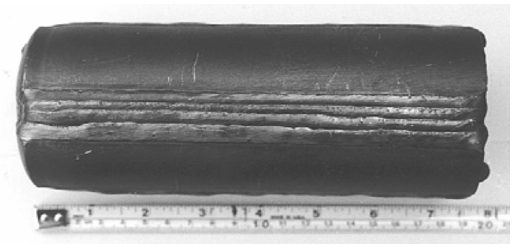
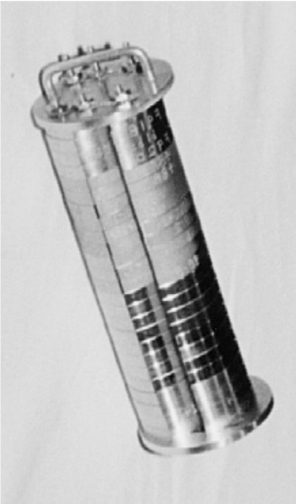
Experimental Procedure









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Compositions (Weight %)

Element	304L Forging (Base)	304L Forging (Welds)	304L Plate*	21-6-9 Forging	308L Filler	309LM Filler	312 M Filler
Cr	18.0	19.9	17.8	19.3	20.5	23.5	28.7
Ni	11.3	10.4	11.1	6.7	10.3	8.55	9.17
Mn	1.7	1.7	1.9	9.9	1.56	1.2	1.45
Mo	.039	0.04	.195	-	<0.01	2.5	0.27
C	.024	0.029	-	.031	0.028	0.02	0.05
Si	.42	0.63	.544	.38	0.5	0.64	0.51
Cu	**-**	**-**	.123	-	0.015	0.31	0.31
P	.007	0.015	.064	.010	0.006	0.022	0.023
S	.003	0.002	-	.001	0.012	0.008	0.008
N	.036	0.039	-	.28	0.055		-
-							
Co	.027	0.03	.065	-	0.068	-	-
O	-	-	-	.002	-	-	-
Al	--	-	-	.004	-	-	-

*304L composition from SRS ICPES analysis; all other heats are manufacturers' supplied compositions.

Weld Ferrite Contents

Sample ID	Base	Filler	Vol % Ferrite
EB	304L Plate	EB Weld	4
48	304L	308L	8
9308	304L Plate	Mix	12
412	304L	312	24
49	304L	309L	33
98	21-6-9	308L	5
912	21-6-9	312	24

*** Average ferrite at center of notch**

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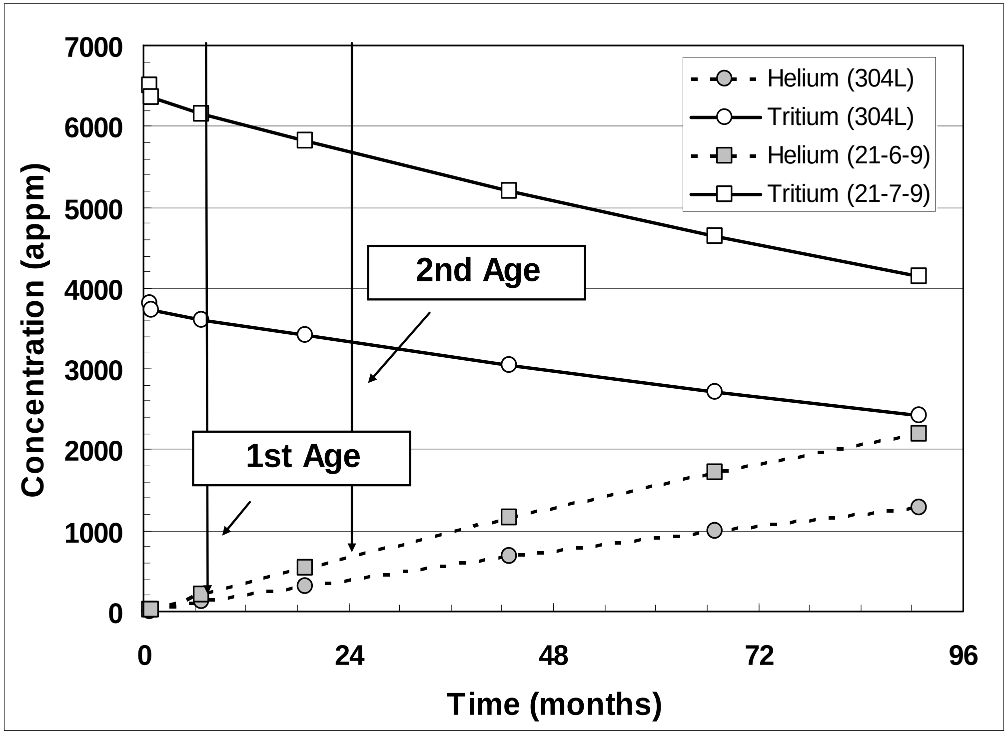
Tritium Exposures and Aging

- Forged 304L & 21-6-9
- Welds of 304L/21-6-9 308L
- Fusion and EB welds
- Six Weld Ferrite Levels
- Exposed at 5000 psi and 350 C
- Goal is to Age to 1000 appm He



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Helium Contents

Material Description	Measured Helium appm	Estimated Original T appm	Age J-Integral Test 1 days	Calculated Helium on Test Date 1 appm	Age J-Integral Test 2 days	Calculated Helium on Test Date 2 appm
Type 304L	129.0	1607	244	60	851	198
Type 21-6-9	161.0	2005	245	75	860	250
HERF 21-6-9	212.0	2641	244	98	860	329
304L EB Weld	86.0	1276	155	30	769	143
304L/308L/312L	84.3	1251	156	30	774	141
304L/308L/309LM	88.7	1316	155	31	774	149
21-6-9/312M	111.0	1383	245	51	-	-
304L/312M	71.3	1058	156	25	769	119
21-6-9/308L	123.0	1532	246	57	295	68
304L/312M	51.9	770	156	18	769	86
304L/308L	-	1532	-	-	760	170
304L/308L	-	1532	-	-	850	189

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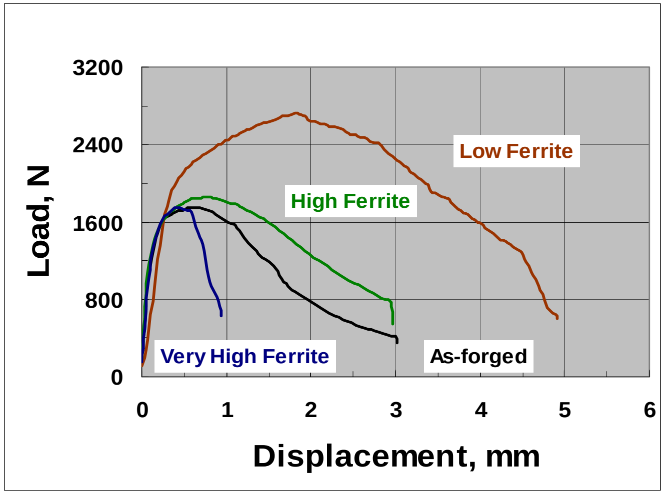
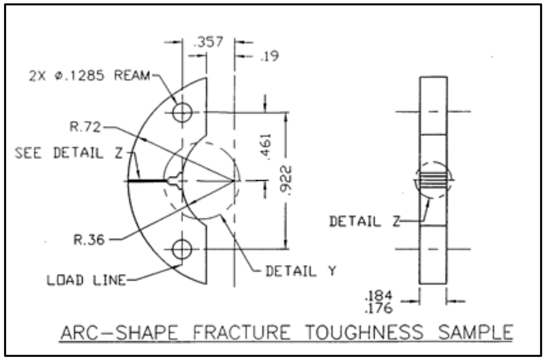
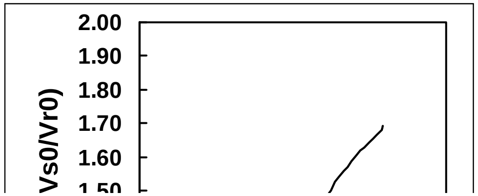
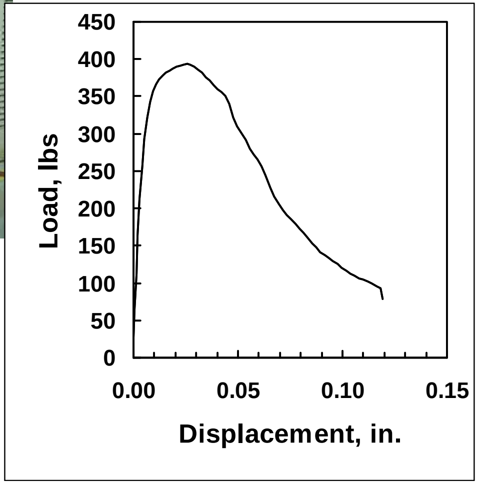
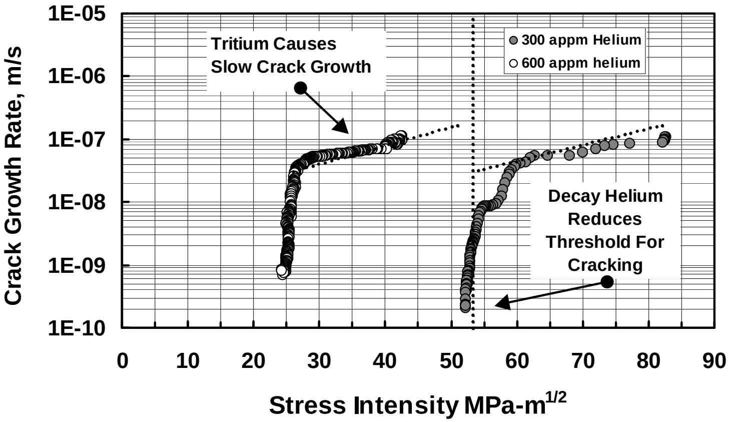
Typical Load-Displacement Records



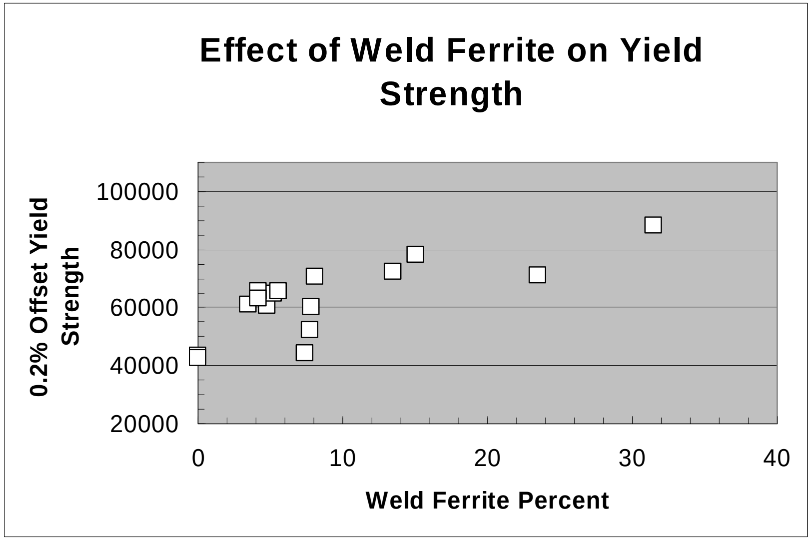


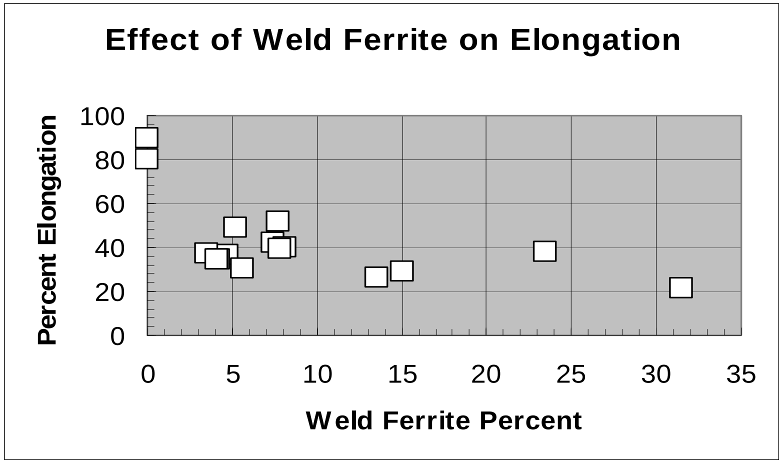


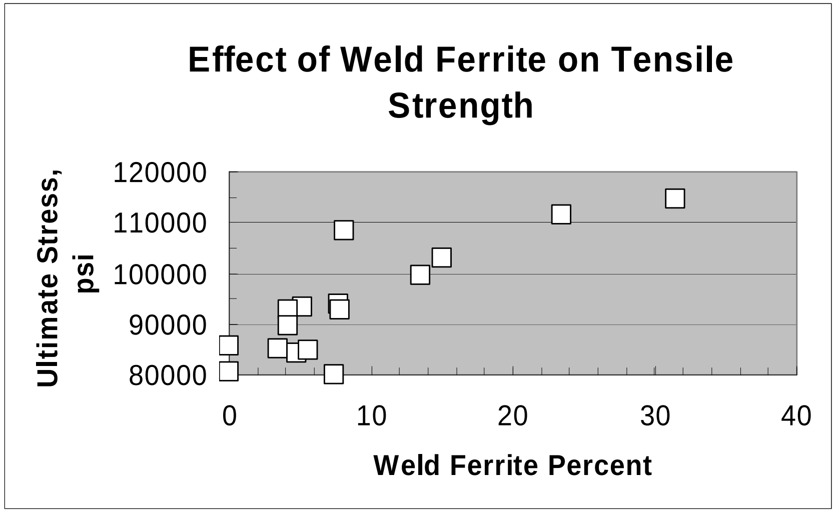


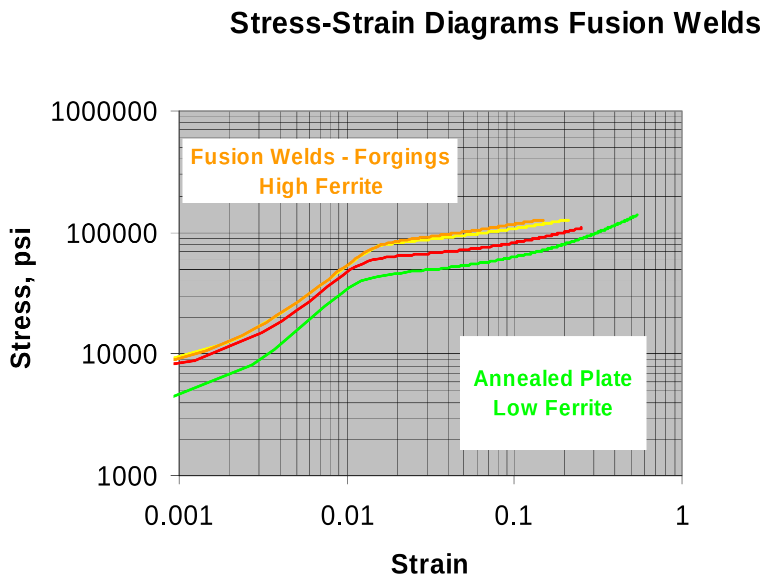


Weldment Tensile Properties

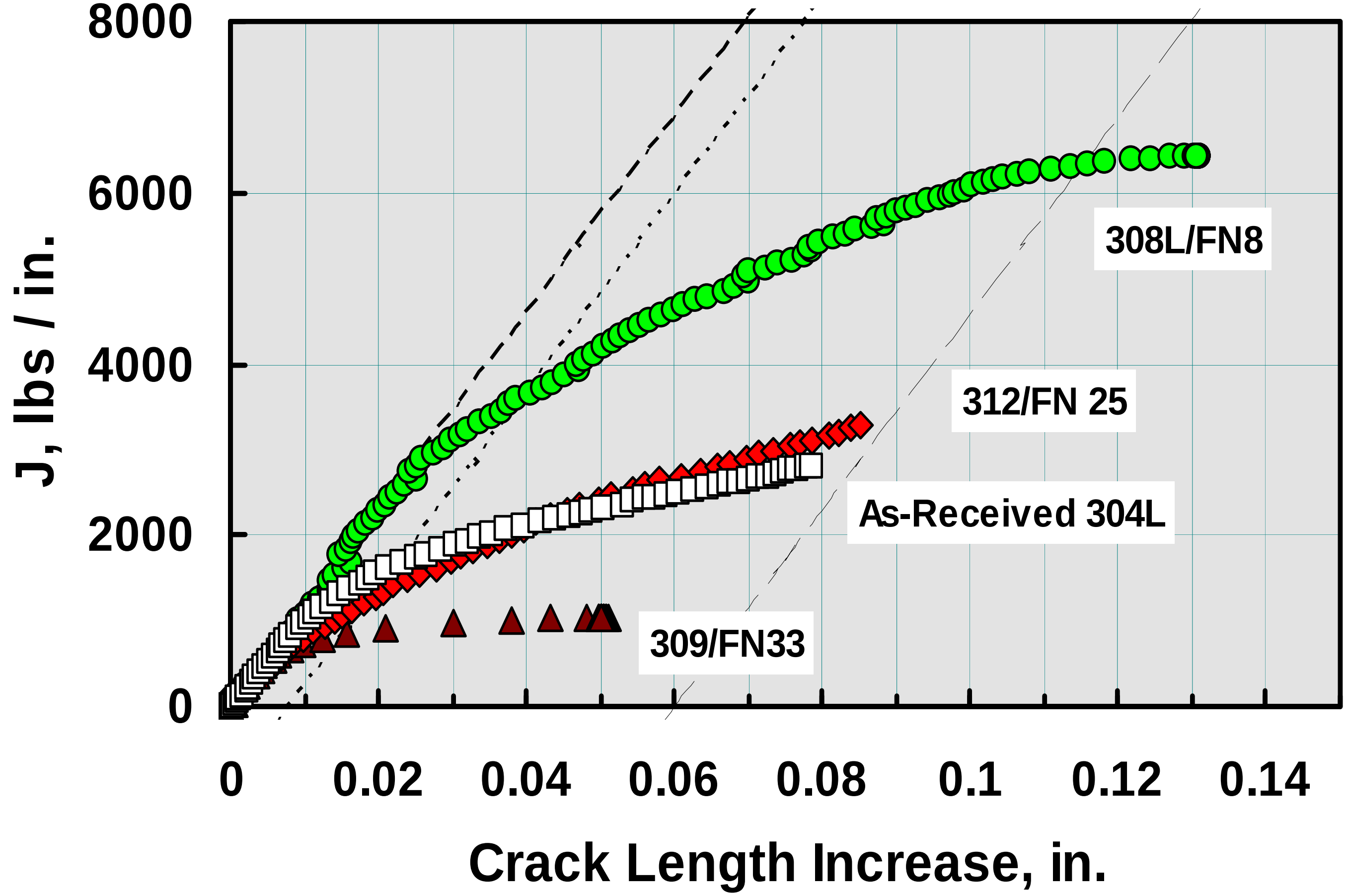








J-R Records 304L Welds



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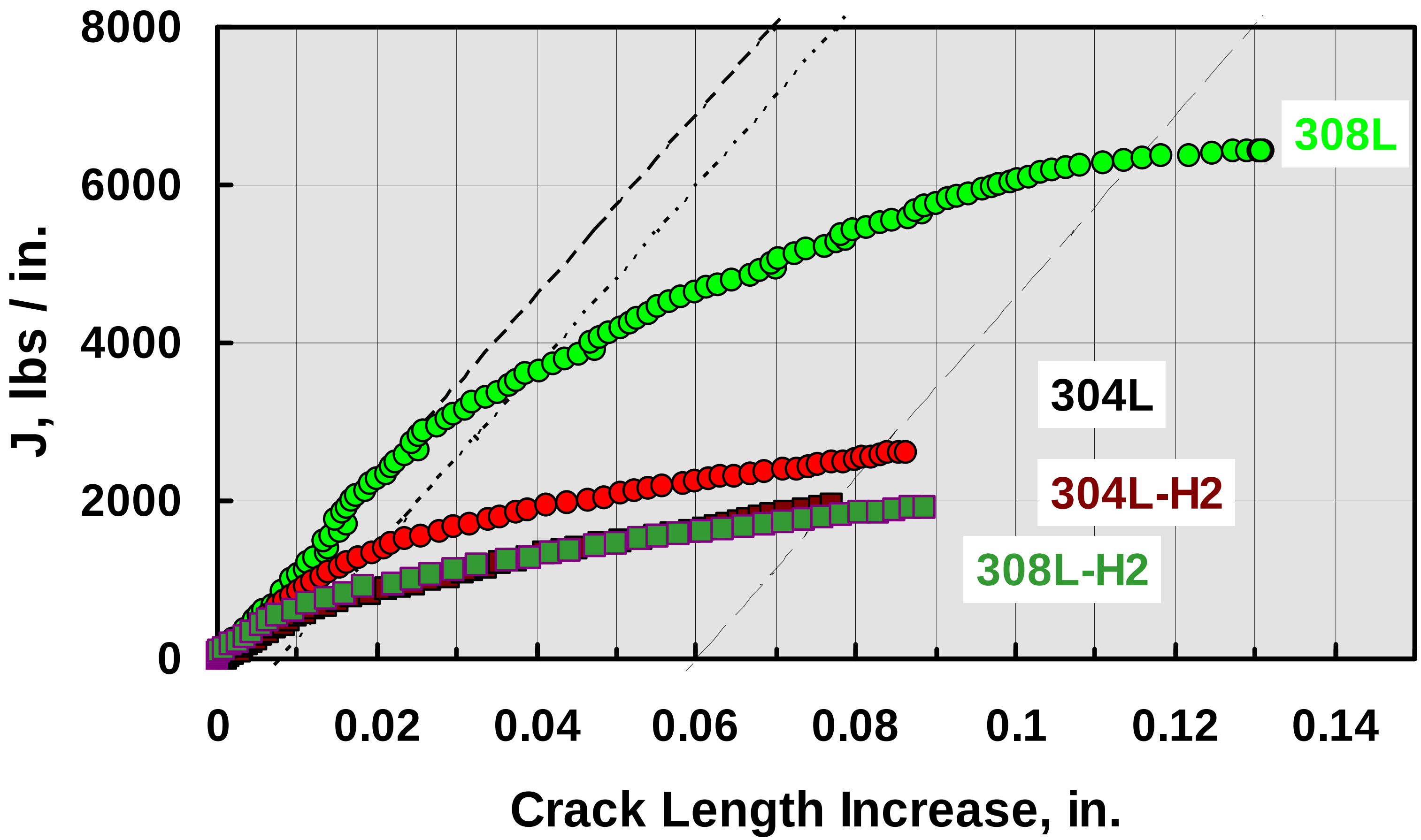
J-R Records: Effect of H_2



Fracture Toughness Values

Material Description	Ferrite %	Yield Strength ksi	Ultimate Strength ksi	J_Q As-Received lbs / in.	J_Q Hydrogen-Charged lbs / in.	J_Q Tritium-Charged-&-Aged 6 Mos. lbs / in.	J_Q Tritium-Charged-&-Aged 30 Mos. lbs / in.
Type 304L	0	67	105	1379	758	942	1014
Type 21-6-9	0	124	146	1024	NA	667	375
304L EB Weld	4	-	-	6000	2216	-	2049
Weldment 21-6-9/308L	6	79	109	5190	652	1715	-
Weldment 304L/308L	8	62	88	4250	770	1244	1434
Weldment 304L/308L/312M	10	66	85	3400	-	1498	1298
Weldment 304L/308L/309LM	13	66	93	3900	-	1177	1222
Weldment 21-6-9/312M	24	71	108	2090	173	510	-
Weldment 304L/312M	25	71	105	1100	172	438	567
304L/309LM	33	83	108	711	71	54	275

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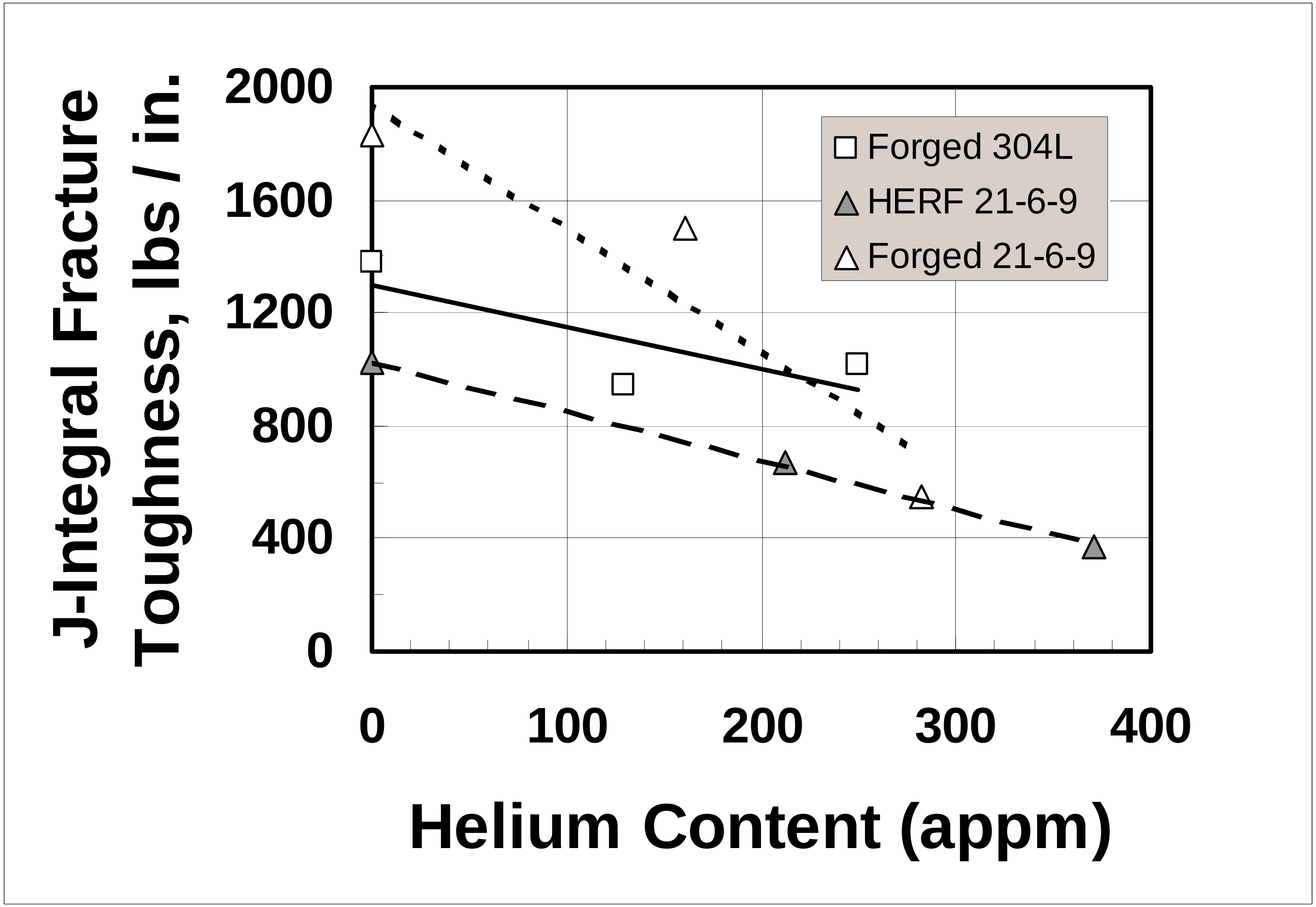
Helium Effect on Toughness of Base Metals



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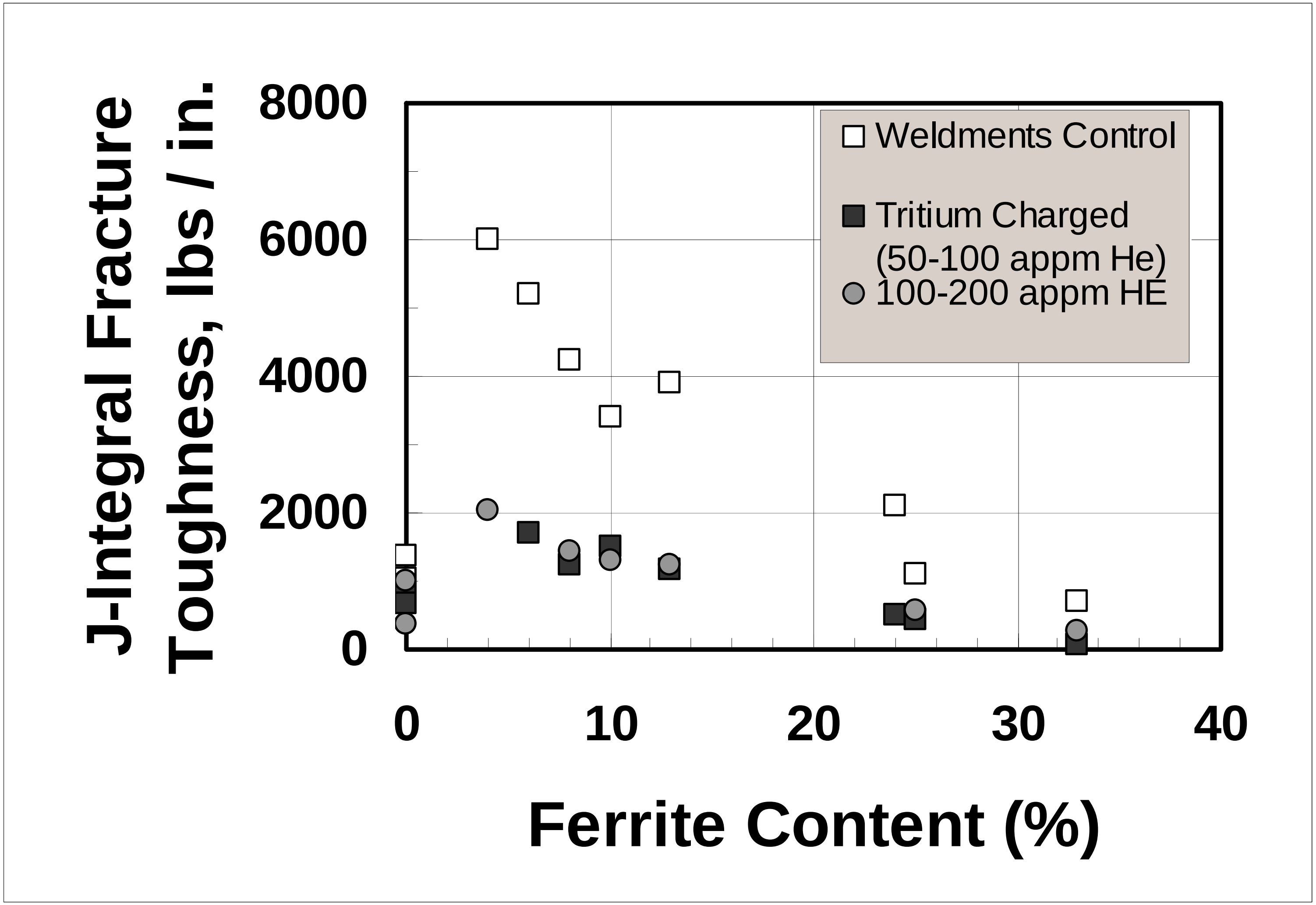
Helium Effect on Toughness of Weldments



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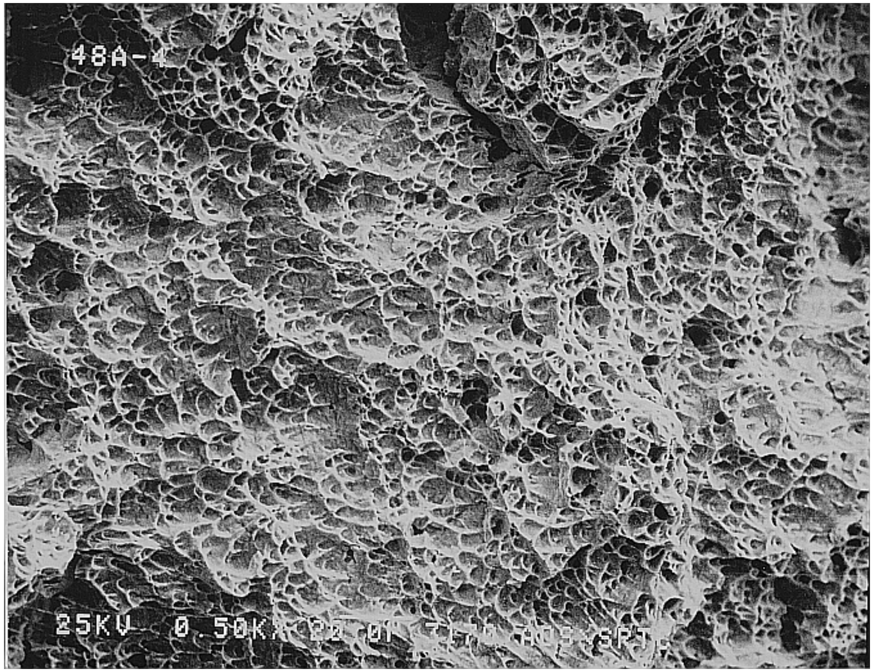
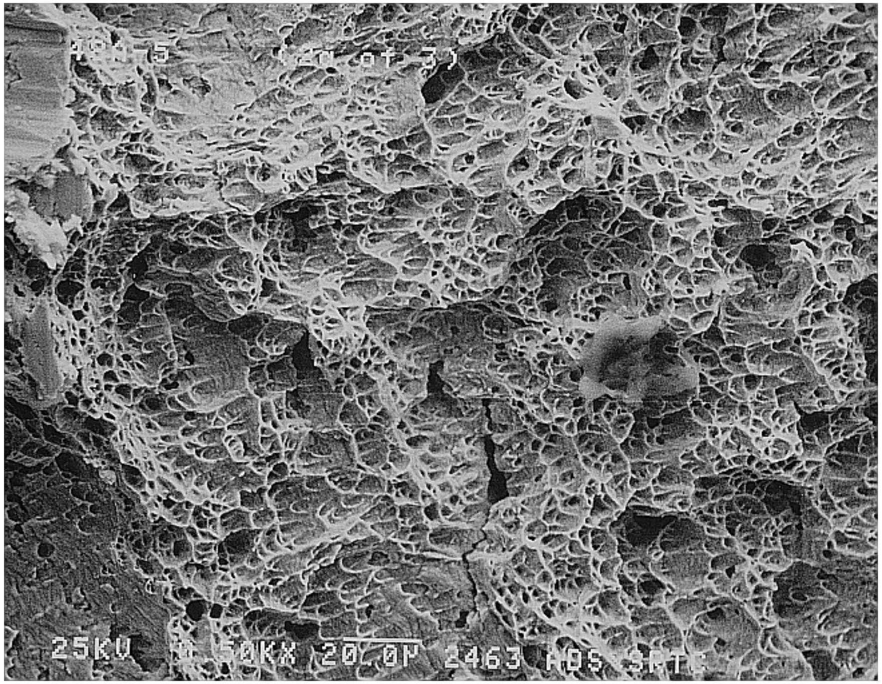
304L Weld Fracture Appearance

308L Filler Normal Weld Ferrite Content





- As-Welded
- H_2-Charged

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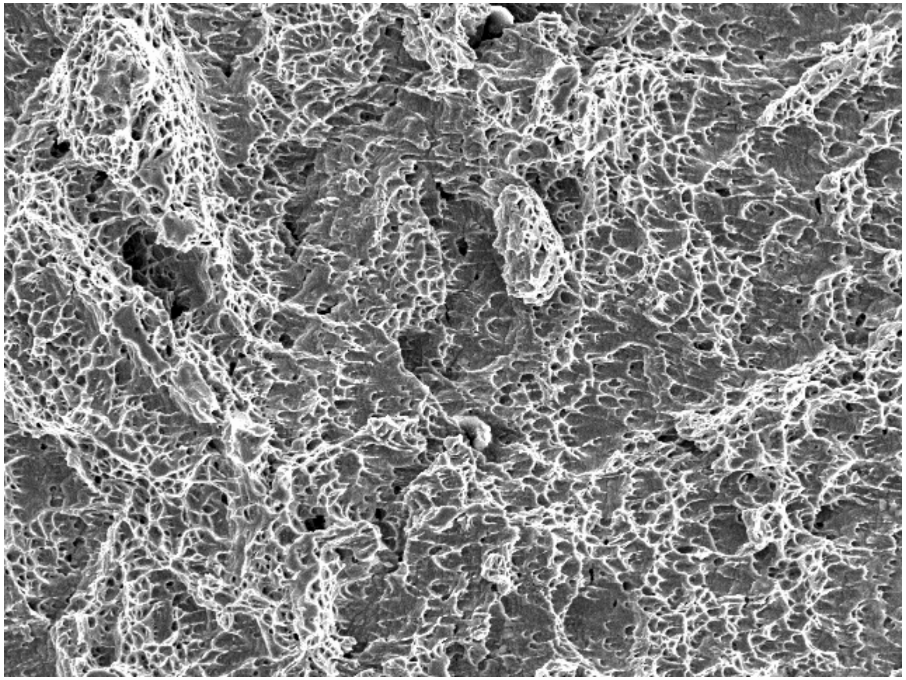
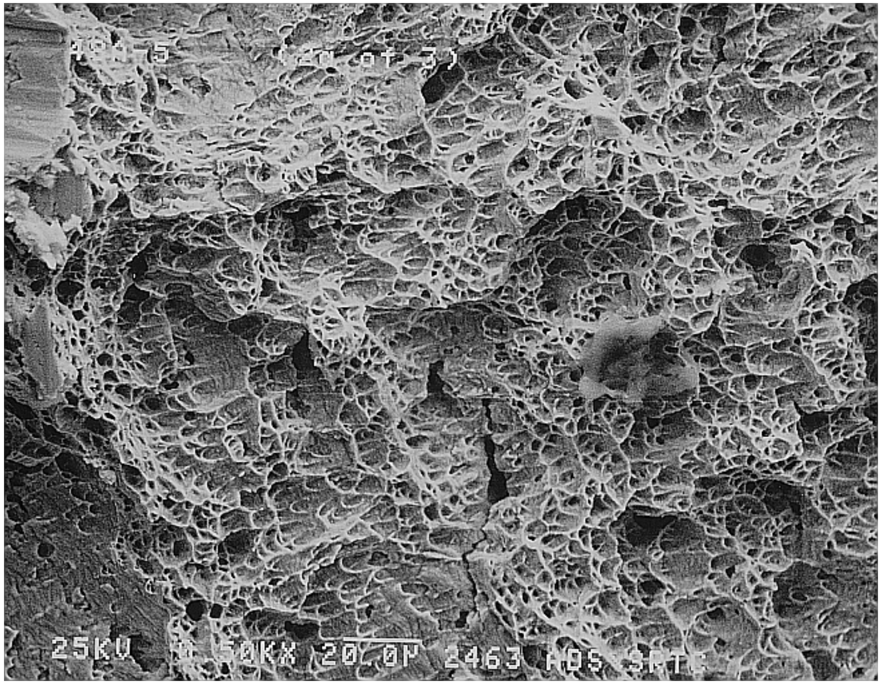
304L Weld Fracture Appearance

308L Filler Normal Weld Ferrite Content

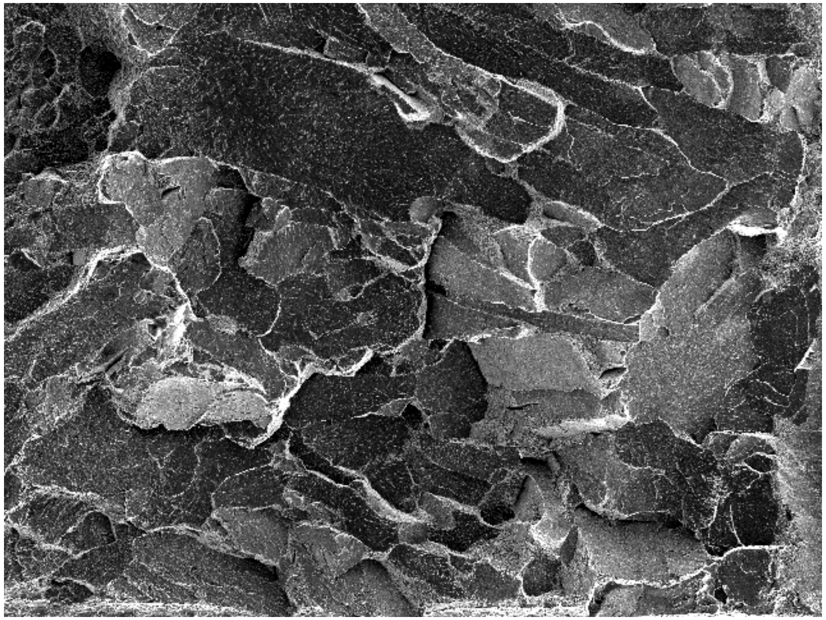




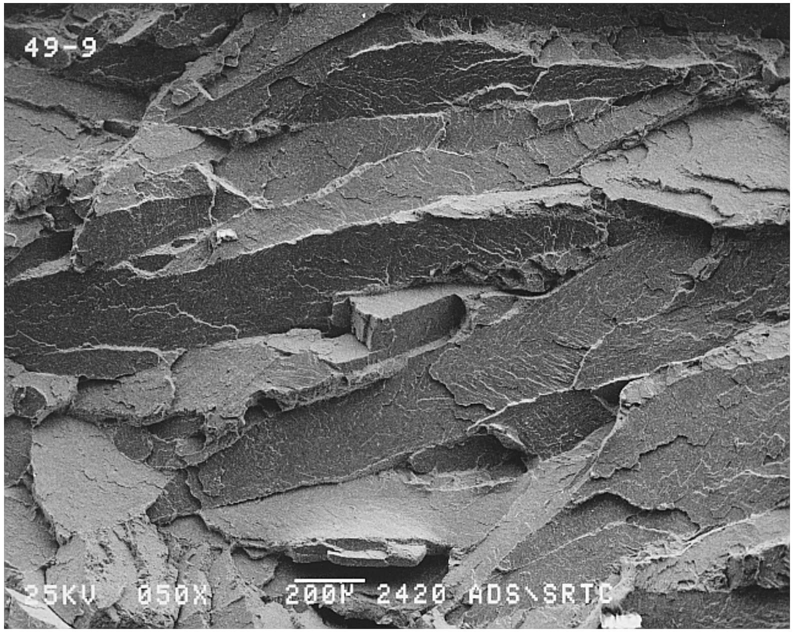
- T2-Charged
- H_2-Charged

Fracture Appearance 304L

309L Filler Very High Ferrite Weld



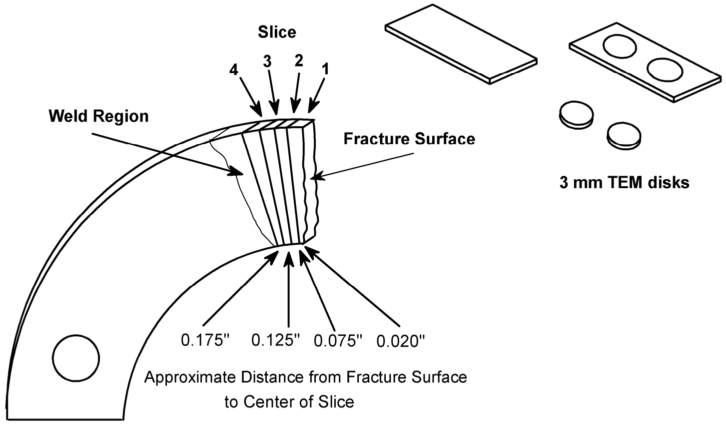
▪T2-Exposed-Aged



▪H_2-Charged

A TEM Study of Helium-Bearing Fusion Welds (U)

- Characterize weld microstructures
- Identify Phases
  - Ferrite/austenite, martensite, others
  - Morphology of ferrite austenite
  - Precipitate distribution
- Characterize Deformation behavior
- Characterize *Helium bubble distribution*



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A TEM Study of Helium-Bearing Fusion Welds (U)

- Summary of Findings
  - Helium bubbles were observed in the austenite
    - Grain interiors and on dislocations
  - Helium bubbles were not observed in the delta ferrite.
    - Small bubble size, and/or
    - Increased tritium diffusivity/decreased solubility in ferrite and losses from outgassing
  - Some BFZs (denuded zones) were observed some austenite/ferrite interfaces – no bubbles on interfaces
  - Fewer bubbles were observed in regions of the weld that contained more ferrite. Related to solubility/diffusivity differences between austenite and ferrite.

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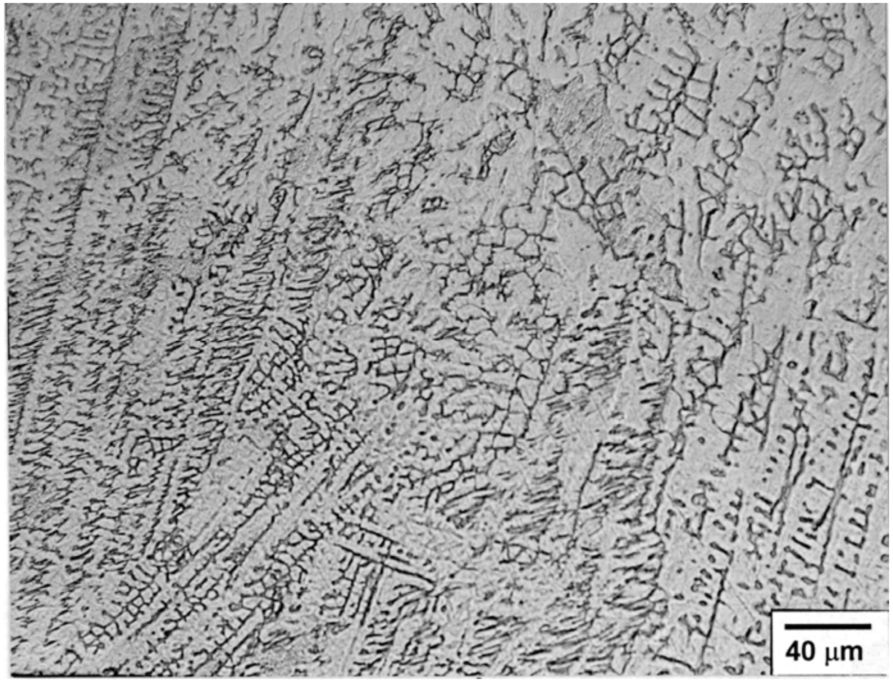
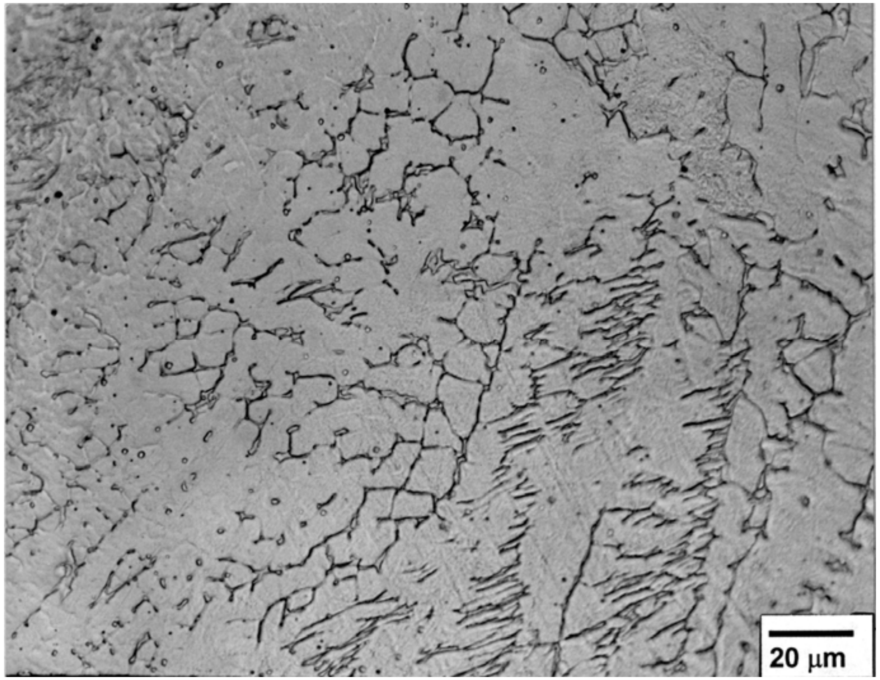
A TEM Study of Helium-Bearing Fusion Welds (U)

21-6-9 Conventional Forging/ 308L Filler Wire





~ 5 vol.% δ ferrite

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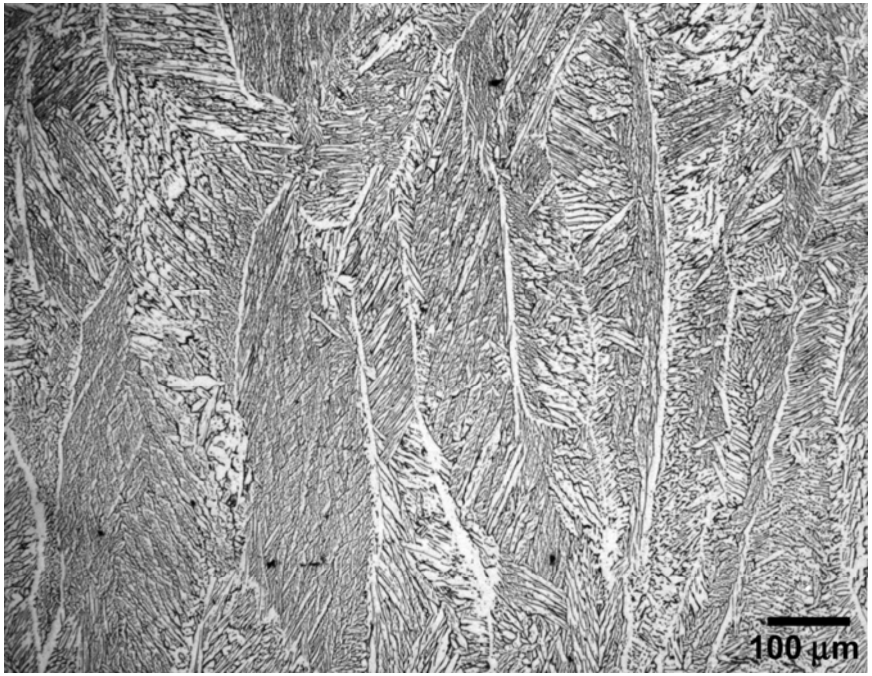
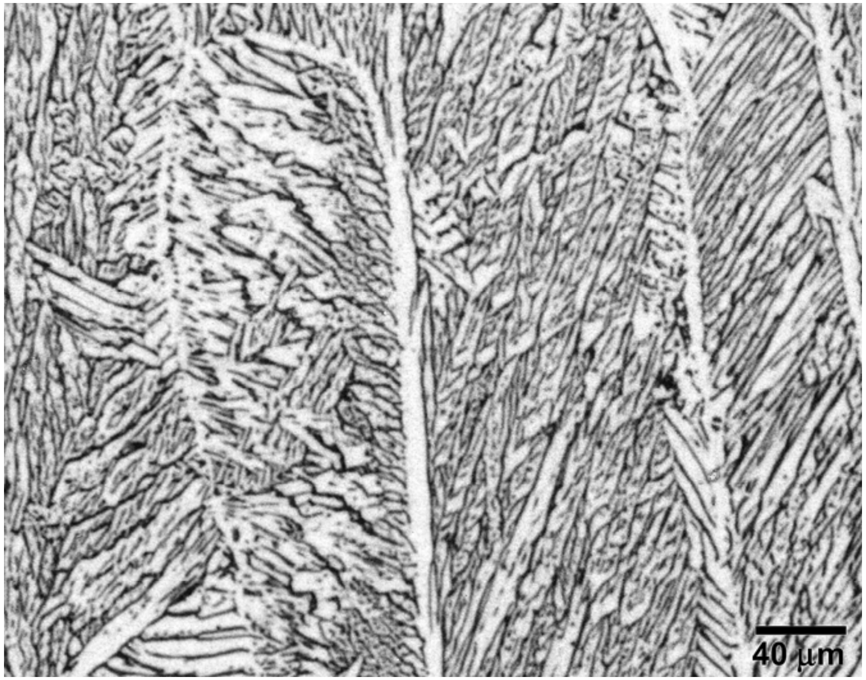
A TEM Study of Helium-Bearing Fusion Welds (U)

304L Weld Critical Plate - 308L/309 MOD Mix





~12 vol.% δ ferrite

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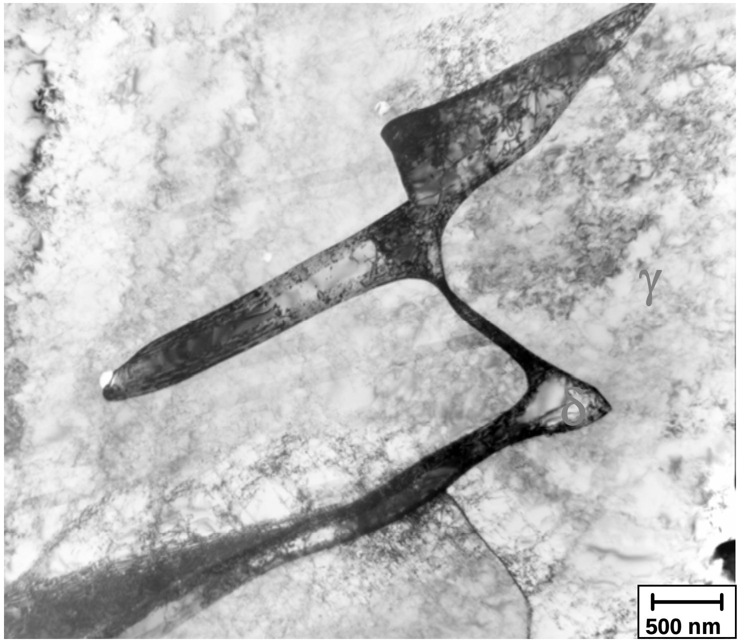
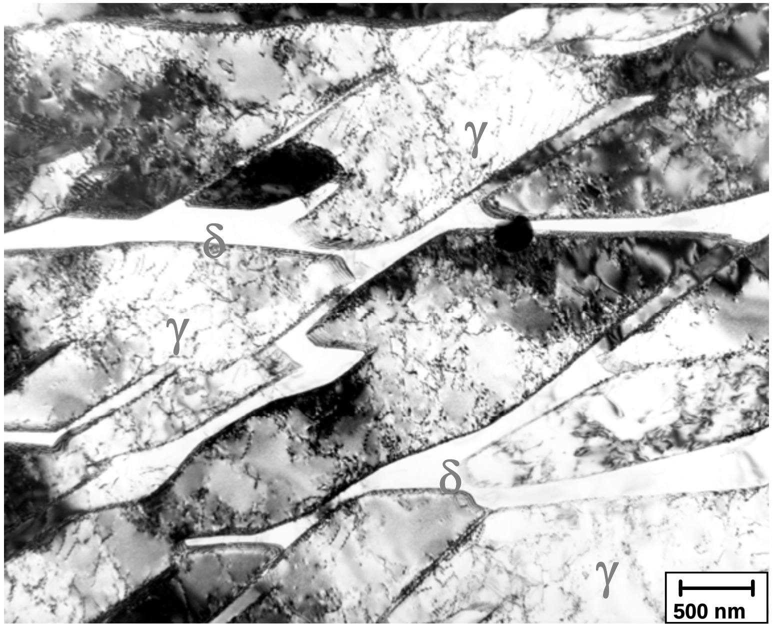
TEM 304L Typical Weld



308L Filler Wire - Low Ferrite Weld



312M Filler Wire - High Ferrite Weld

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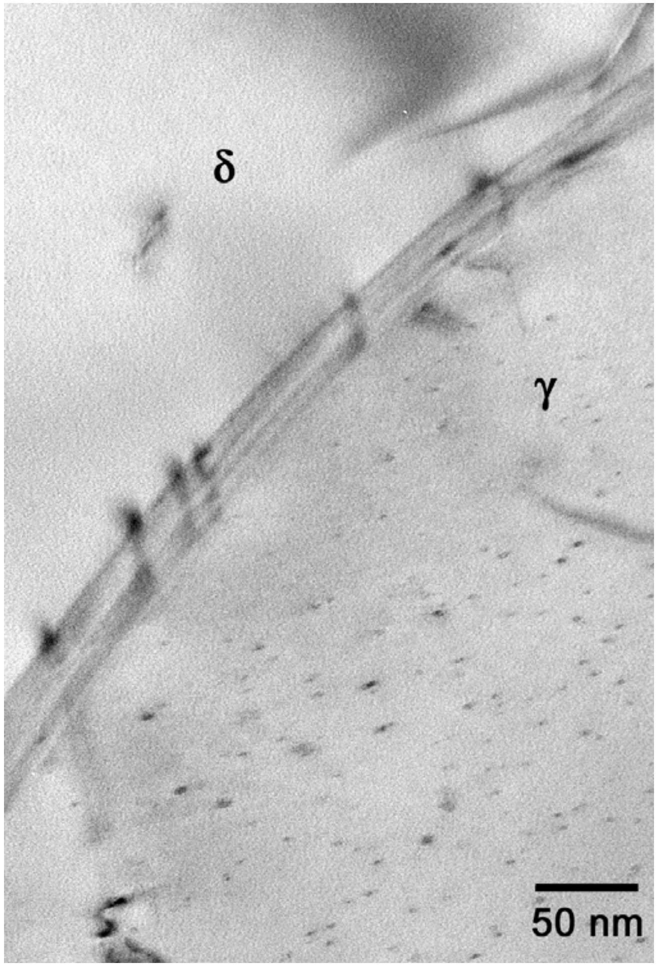
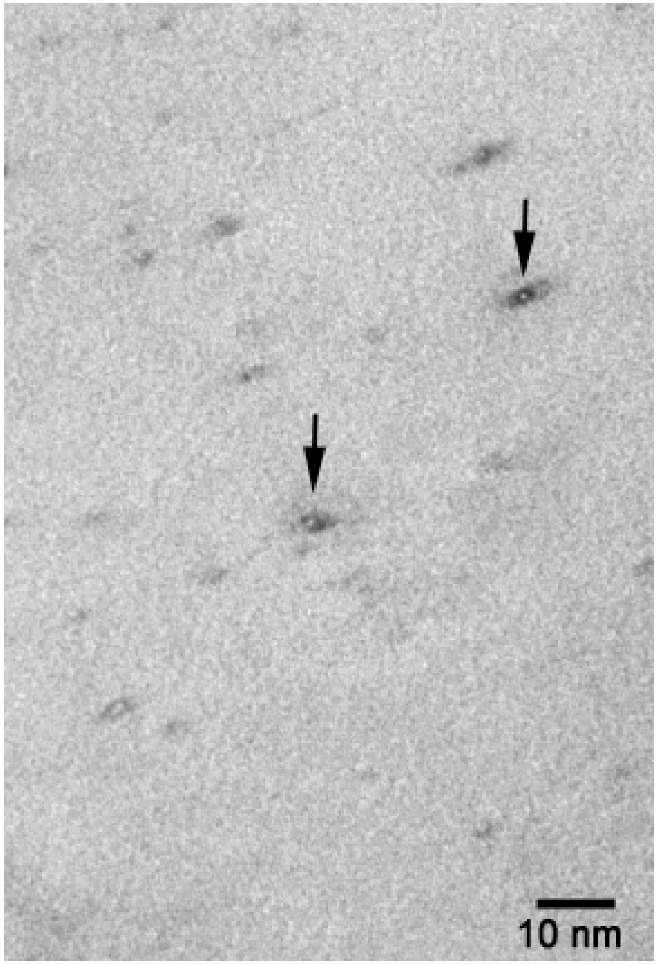
Typical Defect Structure: Tritium-Exposed-Weld



Ferrite/Austenite Interface

Type 304L
Tritium
Low
Ferrite



Helium Bubbles in Austenite

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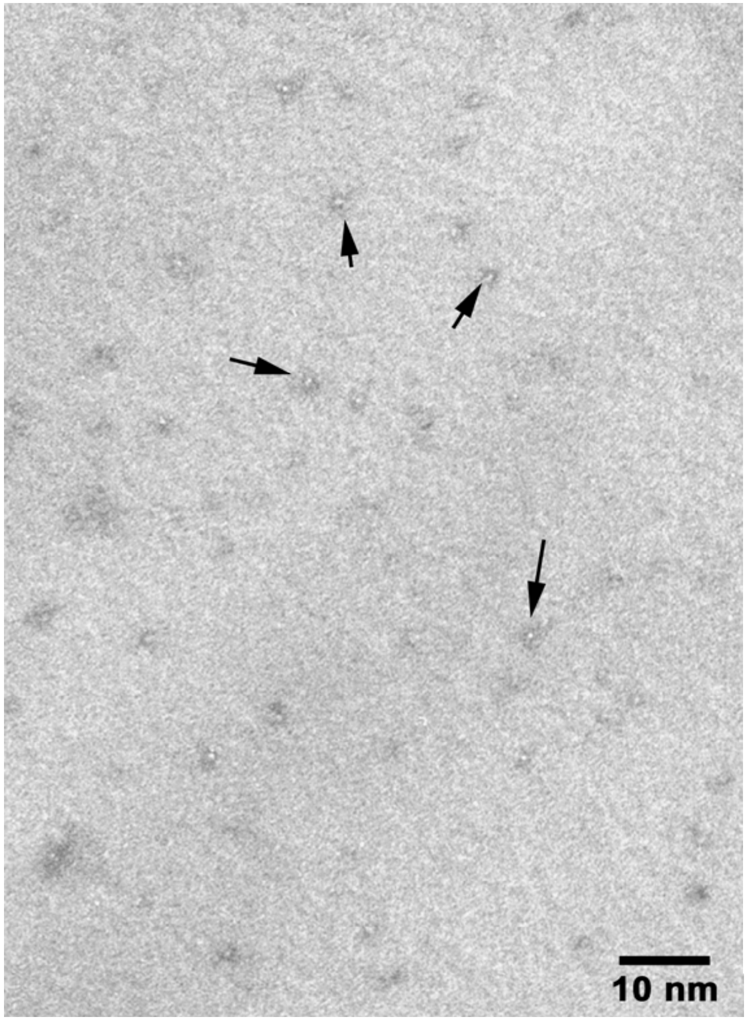
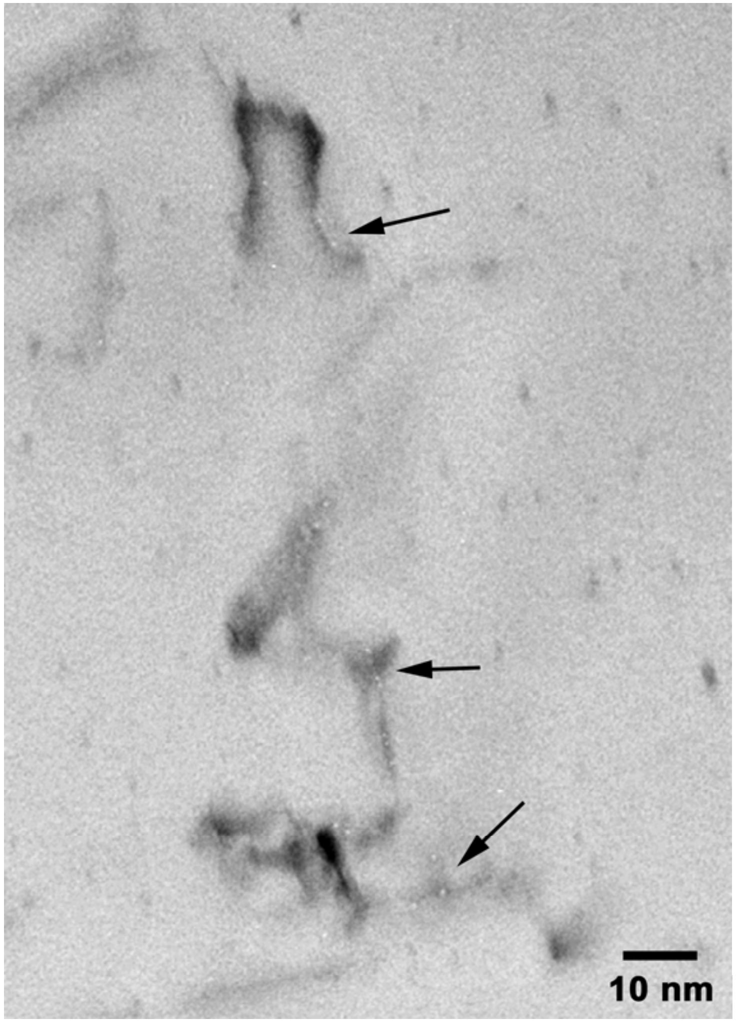
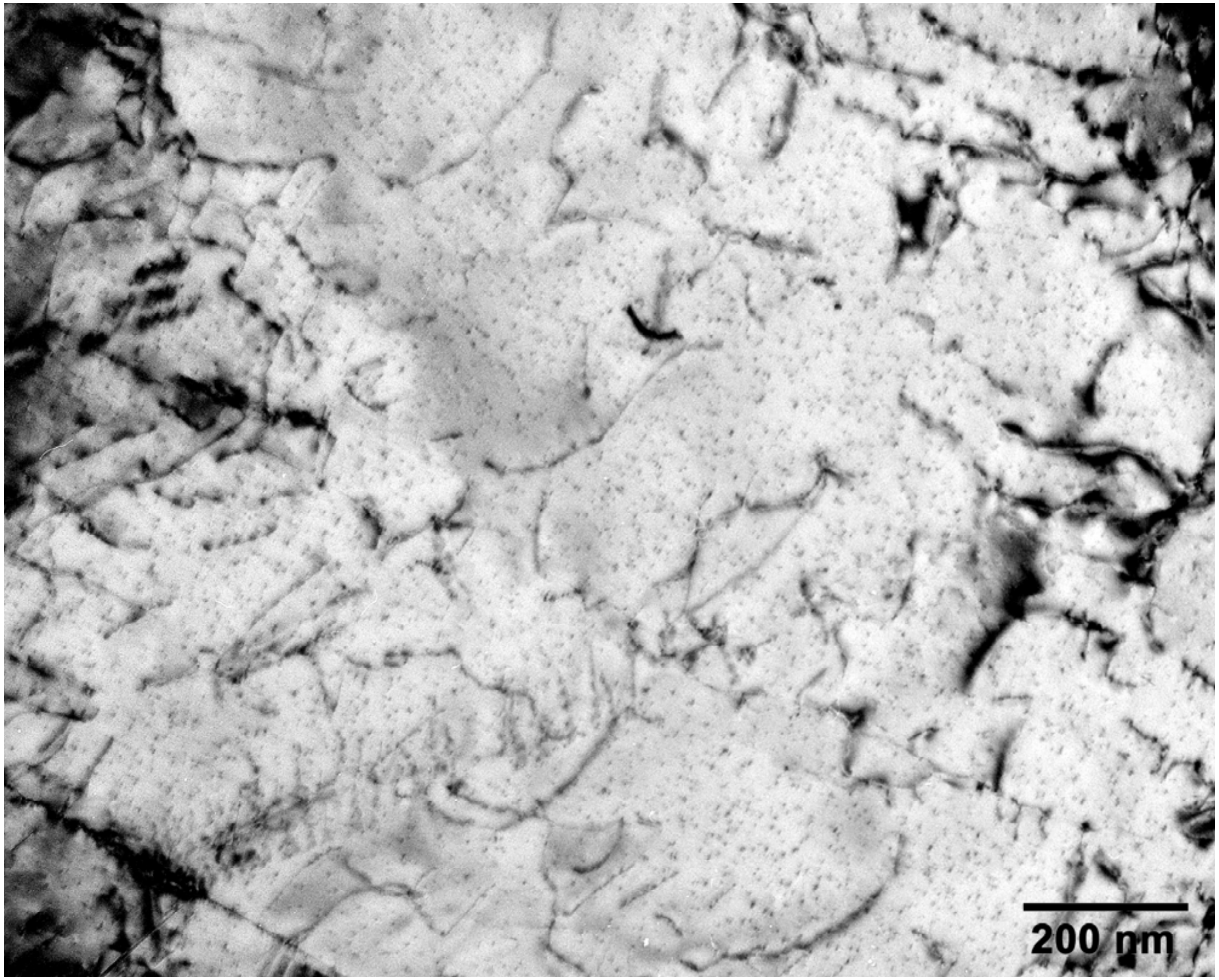
304L Plate – 308L & 309L MOD Wire



304L HERF Forging – 308L Wire



21-6-9 Conventional Forging – 308L Wire



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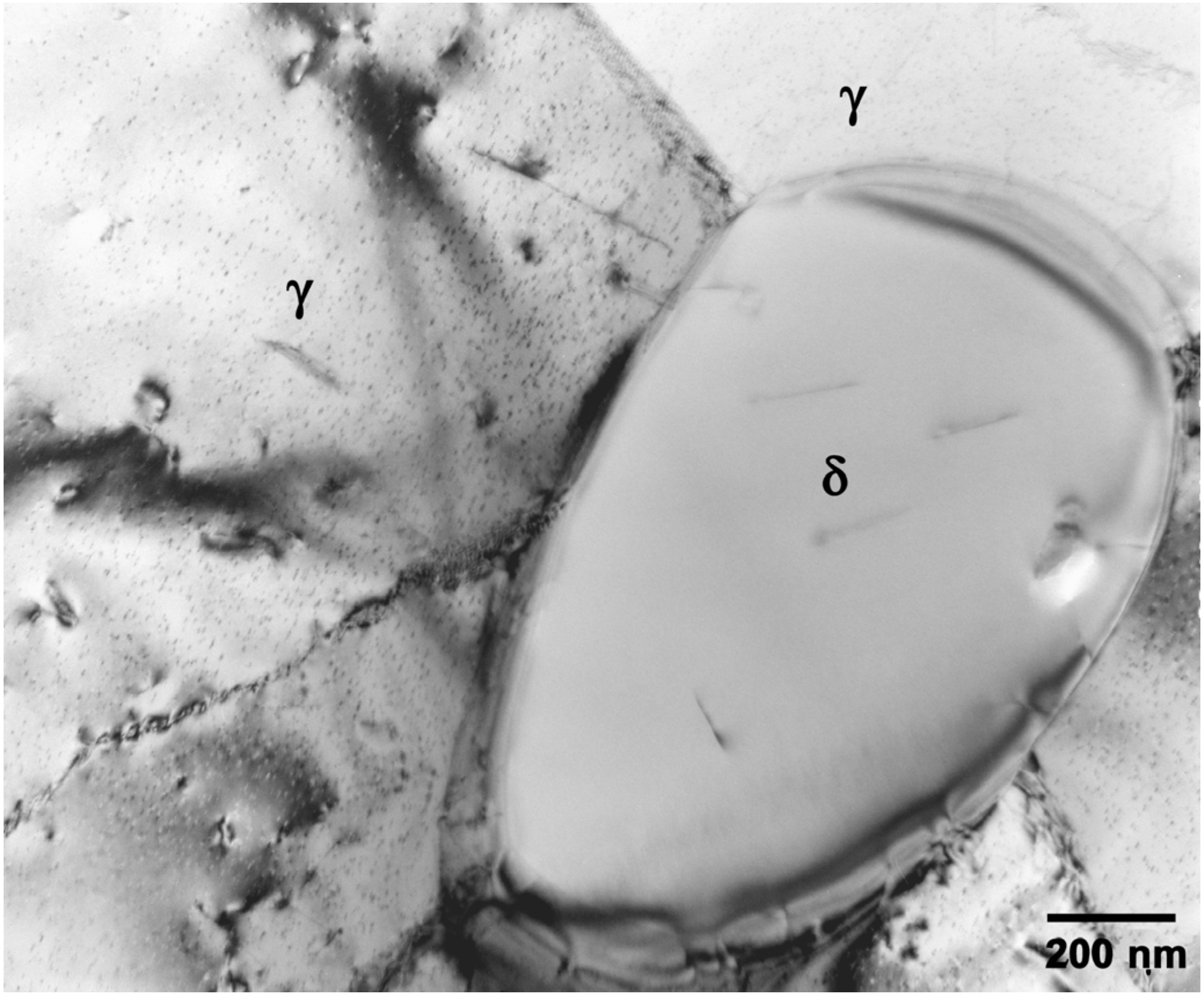
21-6-9 Conventional Forging – 308L Wire



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Summary

- Fracture toughness of weldments was higher than the base metal toughness for weldments with normal weld ferrite contents. Values decreased to about half the base metal value as ferrite content was increased from 8% to 33%.
- Weld microstructure and morphology affected fracture toughness: For discontinuous ferrite, fracture toughness was higher than base metal values; for continuous ferrite, fracture toughness values were lower than base metal values.
- Hydrogen-charged weldments had lower toughness than hydrogen-charged base metals and the toughness decreased with increasing weld ferrite content. Similarly, tritium-exposed-and-aged base metals and weldments had lower toughness than unexposed alloys.
- Base metal toughness decreased with aging time because of increased helium content from tritium decay. Weldment toughness did not decrease with aging time because of tritium off-gassing.
- Fracture modes were dominated by the dimpled rupture process in unexposed steels and welds. In hydrogen and tritium-exposed welds, the fracture modes depended on the weld ferrite content. At high ferrite contents, fracture occurred predominantly by transgranular cleavage through the weld ferrite phase.

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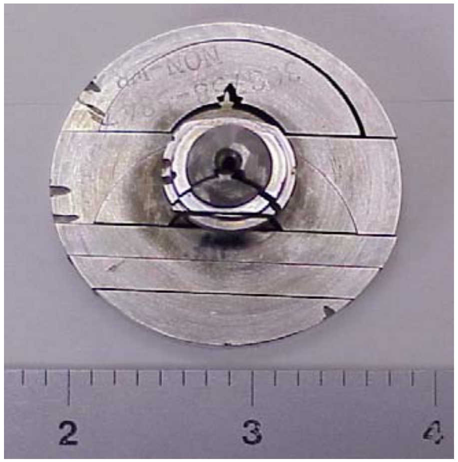
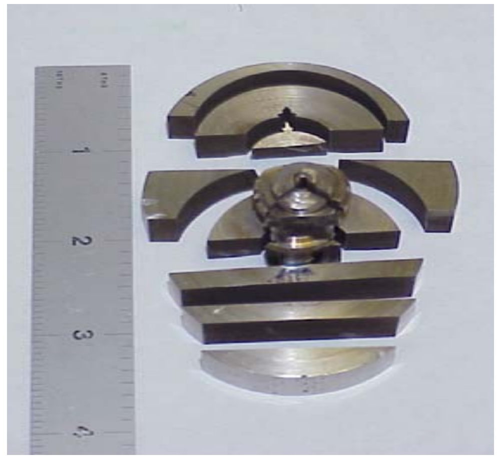
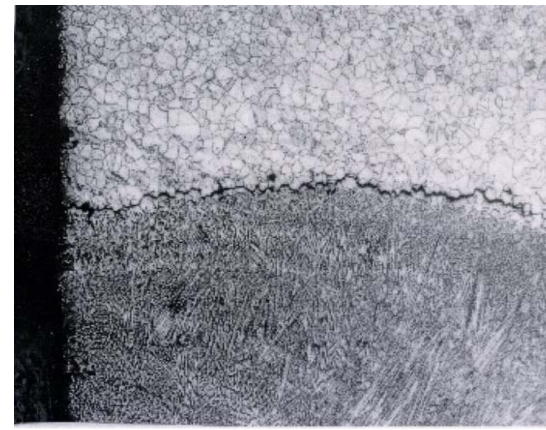
Future Work

Properties of Components (Location and Orientation)



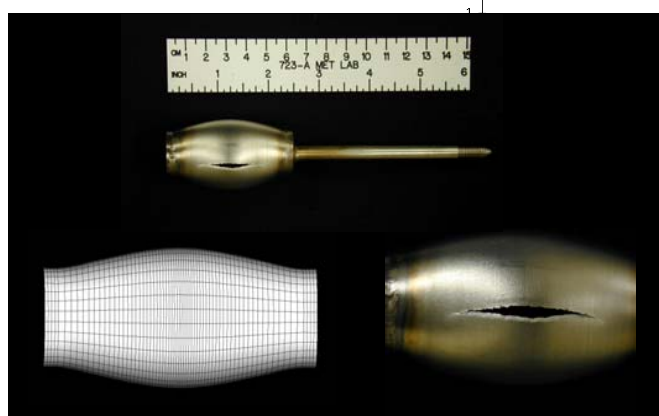


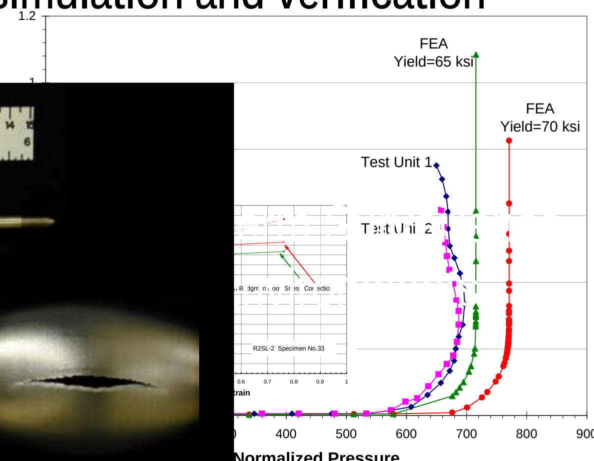
Heat Affected Zones



Testing in High Pressure Hydrogen

Inputs for simulation and verification





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